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THE EFFECTS OF THREE-DIMENSIONAL IMPOSED DISTURBANCES ON BLUFF BODY NEAR WAKE FLOWS

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A project in the Accelerated Research Initiative "Wake Vortex Dynamics

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PROJECT ABSTRACT

Research Goals:

To achieve a better understanding of the underlying three-dimensional flow structure in the near wake of a nominally two- dimensional bluff body. To understand the effects of three-dimensional features that are characterised by vortex splitting and looping on wake parameters such as base pressure, vortex shedding frequency, wake width and vortex formation length. An underlying aim is to investigate why, for Reynolds numbers greater than a few hundred, some flow quantities predicted by two-dimensional numerical simulations of bluff body flows are not always in good agreement with experiment.

Objectives:

1. To control the occurrence of three-dimensionality in the shed vortices by applying mild three-dimensional geometric disturbances along the span.

2. To study the effects of geometric disturbances on wake parameters such as: Strouhal number, base pressure and vortex formation length.

3. To visualise vortex dislocations and the various modes of shedding.

4. To understand the dynamics of vortex dislocations.

Approach:

The basic body shape studied was a half ellipse model with a blunt trailing edge. The thickness to chord ratio was roughly 16% and the boundary layers were tripped at a position 20% of the chord from the leading edge. A series of trailing edge geometries were studied including a straight edge and sinusoidal trailing edges with different numbers of wavelengths across the span and with a range of wave heights. The purpose of the wavy trailing edges was to fix the positions of dislocations of the vortices shed from the body. The three-dimensional structure of the near wake

was investigated using wind tunnel and water tunnel experiments. Experiments were carried out in a 0.91m x 0.91m closed return, low speed wind tunnel and the Reynolds number range, using model base height as reference length, was 20,000 to 60,000. Flow visualisation was performed at a Reynolds number of 2,500 in a water flume with a cross section 0.6m x 0.6m. Measurements of velocity fluctuations and mean and fluctuating pressures as well as flow visualisation studies have been carried out to reveal the three-dimensional features present in wakes.

Tasks Completed:

Measurements have been carried out on a blunt trailing edge model with a straight trailing edge and with a sinusoidal trailing edge. Experiments were conducted in a 0.91mx0.91m wind tunnel for Reynolds numbers, based on model trailing edge thickness, of 20,000 to 60,000. Flow visualisation using the electrolytic precipitation method was performed in a water channel 0.6mx0.6m at a Reynolds number of 2,500. A video film has been made to illustrate vortex dislocations and the various vortex shedding modes.

Mean and fluctuating pressures on the bases of the models have been recorded and fluctuating velocities have been measured in the near wake region.

A model for the dynamics of the vortex formation region that accommodates variations in flow quantities along the span has been devised. Vortex dislocations have been studied and a mechanism has been proposed that explains the occurrence of a characteristic dislocation frequency in the near wake. A link between this dislocation frequency and fluctuations in base pressure and vortex strengths has been found.

Scientific Results:

The most notable feature of the flow behind the sinusoidal trailing edge model is the appearance of two vortex shedding frequencies. The higher frequency dominates the flow at a valley in the sinusoidal trailing edge while at a peak the two frequencies coexist. In order for this to happen vortex splitting must occur in the near wake.

Flow visualisation shows that more than one shedding mode exists for the sinusoidal model. Vortex splitting is observed to occur regularly in the region of a peak, but at the two neighbouring valleys vortex shedding can be in phase (symmetric mode), or out of phase (three-cell antisymmetric mode). A two-cell antisymmetric mode and an oblique mode are also observed in the water channel experiments. It is believed that the transition from one mode to another has to follow a prescribed gradual change and cannot happen between all combinations of modes. The flow visualisation study also revealed pairs of opposite sign longitudinal vortices in the separated shear layers which wrap around the main von Karman type vortices.

The frequency of vortex splitting, or the dislocation frequency, is at the difference frequency between vortex shedding at a peak and a valley. In general, for vortices to join with similarly signed vortices on the other side of a dislocation (at times these vortices may be 180 degrees out of phase), they have to bend. This bending causes fluctuations in the vortex formation length at the dislocation frequency. This in turn results in low frequency variations in the base pressure on the body. In order to meet across a dislocation , vortices from the two sides have to bend in opposite directions and this implies that on one side the vortex formation length will grow and on the other it will shrink. This helps to explain the presence of sharp spanwise gradients in the base pressure.

Behind the sinusoidal trailing edge body there is a tendency for the vortices to straighten out. This means that at a valley the formation length will be larger than that at a peak and this is observed in

the experiments. As a result of the longer formation length it is expected that the fraction of the vorticity shed from the body that survives formation and is found in the vortices will be smaller. If the circulation of the Karman vortices is to be constant along the span, i.e. there is to be no vortex looping, then more vorticity has to be generated and shed at a valley. Measurements of the time mean base pressure show it to be lower at a valley than a peak hence indicating that more vorticity is shed at a valley.

Although the flow is three dimensional quasi two-dimensional arguments based on wake similarity still seem to work. A near constant value of a universal Strouhal number based on wake width and flow separation velocity was found for different spanwise positions.

Accomplishments:

It has been found that:

1. Vortex dislocations are a fundamental feature of the wakes of two-dimensional bluff bodies at high Reynolds numbers and need to be simulated by CFD codes.

2. The location and timing of vortex dislocations can be controlled by introducing mild three-dimensional geometric disturbances.

3. With a sinusoidal trailing edge different vortex shedding frequencies are observed in the valleys and in the peaks. Dislocations occur at a frequency equal to the difference between these two frequencies.

4. The concept of a constant universal Strouhal number holds even when the flow is three dimensional.

PUBLICATIONS FROM ONR SPONSORED WORK

Bearman, P.W. and Tombazis, N., The Effects of Three-Dimensional Imposed Disturbances on Bluff Body Near Wake Flows. Second International Colloquium on Bluff Body Aerodynamics and Applications, Melbourne, December 1992.

Tombazis, N., Effects of Three-Dimensional Disturbances on Bluff Body Near Wakes. PhD Thesis, University of London, March 1993. (Submitted as a full report on the work carried out at Imperial College)

Bearman, P.W., Challenging Problems in Bluff Body Wakes. "Bluff Body Wakes, Dynamics and Instabilities", Eds. H.Eckelmann, J.M.R.Graham, P.Huerre, P.A.Monkewitz, pp 1-10, Springer-Verlag, 1993.

Bearman, P.W. and Tombazis, N., The Effects of Three-Dimensional Imposed Disturbances on Bluff Body Near Wake Flows. J Wind Eng and Indust Aero, vol 49, pp 339-350, 1993

Tombazis, N and Bearman, P.W., Effects of Three-Dimensional Disturbances on Bluff Body Near Wakes. To be submitted to the Journal of Fluid Mechanics.